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Stylesheet Version v1.1.1

Claims

[c1] A Bishop Process heat exchanger comprising:

at least one elongate inner conduit, at least a portion of which is formed from cryogenically compatible materials;

an outer conduit surrounding at least a portion of the inner conduit, the outer conduit formed from non-cryogenically compatible materials;

a plurality of centralizers mounted inside the outer conduit to position the inner conduit generally in a coaxial relationship with the outer conduit to define an annular passageway for a warmant;

a pump system to circulate warmant through the annular passageway between the inner conduit and the outer conduit;

a high pressure pumping system to raise the pressure of a cold fluid to change it to a dense phase fluid and to move the dense phase fluid through the inner conduit; and

the inner conduit formed from a material that is strong enough to withstand the high pressure of the dense phase fluid from the high pressure pumping system.

[c2] The apparatus of claim 1 wherein the pressure of the cold fluid is sufficient to create a Froude Number in excess of 10 in the heat exchanger.

[c3] The apparatus of claim 1 wherein the inner conduit includes a plurality of conduits positioned by the centralizers in a generally coaxial relationship

with the outer conduit.

[c4] A Bishop Process heat exchanger comprising:

at least one elongate inner conduit, at least a portion if which is formed from cryogenically compatible materials;

an intermediate conduit surrounding at least a portion of the inner conduit, the intermediate conduit formed from cryogenically compatible materials;

an outer conduit surrounding at least a portion of the intermediate conduit, the outer conduit formed from not-cryogenically compatible materials;

a plurality of centralizers mounted inside the intermediate conduit to position the inner conduit generally in a coaxial relationship with the inner conduit to defining a first annular passageway;

a second set of centralizers mounted inside the outer conduit, to position the intermediate conduit generally in a coaxial relationship with the outer conduit to define an second annular passageway for a warmant;

a pump system to circulate warmant through the second annular passageway and the inner conduit;

a high pressure pumping system to raise the pressure of a cold fluid to change it to a dense phase fluid and to move the dense phase fluid through the first annular passageway; and

the inner conduit and the intermediate conduit formed from a material that is strong enough to withstand the high pressure of the dense phase fluid from the high pressure pumping system.

[c5] The apparatus of claim 4 wherein the flow characteristics in the heat

exchanger are sufficient to create a Froude Number in excess of 10 during operation.

[c6] A Bishop Process heat exchanger comprising:

at least one elongate inner conduit, at least a portion of which is formed from cryogenically compatible materials;

an outer conduit surrounding at least a portion of the inner conduit, the outer conduit formed from non-cryogenically compatible materials;

a plurality of positioners mounted inside the outer conduit to position the inner conduit generally in a coaxial relationship with the outer conduit to define a generally annular passageway for a warmant;

a warmant pump system to circulate warmant through the annular passageway between the inner conduit and the outer conduit, the warmant selected from the group consisting of seawater, fresh water, and warmants from industrial processes;

a high pressure pumping system to raise the pressure of a LNG in excess of 1200 psig to convert it to a dense phase natural gas (DPNG) and to move the DPNG through the inner conduit;

the inner conduit formed from a material that is strong enough to withstand the pressures of the DPNG from the high pressure pumping system; and

the heat exchanger having a Froude Number in excess of 10 during operation.

[c7] The apparatus of claim 6 wherein the inner conduit if formed from a nickel steel alloy.

[c8] The apparatus of claim 6 wherein the outer conduit is formed from a group consisting of plastic and fiberglass.

[c9] The apparatus of claim 6 wherein the flowpath of the DPNG and the warmant through the heat exchanger is generally parallel.

[c10] The apparatus of claim 6 wherein the flowpath of the DPNG and the warmant through the heat exchanger are generally counter to each other.

[c11] The apparatus of claim 6 further including a flexible joint at an end of the inner conduit to facilitate connection of the cryogenically compatible inner conduit with a non-cryogenically compatible downstream piping system.

[c12] The apparatus of claim 6 wherein the heat exchanger has a serpentine pattern to reduce the overall footprint of the heat exchanger.

[c13] A Bishop Process heat exchanger comprising:

a first section having:

at least one elongate inner conduit, at least a portion of which is formed from cryogenically compatible materials;

an outer conduit surrounding at least a portion of the inner conduit, the outer conduit formed from non-cryogenically compatible materials;

a plurality of positioners mounted inside the outer conduit to position the inner conduit generally in a coaxial relationship with the outer conduit to define a generally annular passageway for a warmant;

a first warmant pump system to circulate warmant through the annular passageway in the first section of the heat exchanger;

a second section having:
at least one elongate inner conduit, at least a portion of which is formed from cryogenically compatible materials;
an outer conduit surrounding at least a portion of the inner conduit, the outer conduit formed from non-cryogenically compatible materials;
a plurality of positioners mounted inside the outer conduit to position the inner conduit generally in a coaxial relationship with the outer conduit to define a generally annular passageway for a warmant;
a second warmant pump system to circulate warmant through the annular passageway in the second section of the heat exchanger;
a high pressure pumping system to raise the pressure of a LNG in excess of 1200 psig to convert it to a dense phase natural gas (DPNG) and to move the DPNG through the inner conduit in both the first and second sections of the heat exchanger; and
the heat exchanger having a Froude Number in excess of 10 during operation.

[c14] The Bishop Process heat exchanger of claim 13 wherein the high pressure pumping system including a plurality of pumps each having a nominal pumping rate of 2,200gpm at a pressure in excess of 1800 psig with total horsepower requirements for the high pressure pumping system being in excess of 24,000.

[0015] Uncompensated salt caverns for natural gas storage preferably operate in a temperature range of approximately +40ºF to +140ºF and pressures of 1500 to 4000 psig. If a cryogenic fluid at sub-zero temperature is pumped into a cavern, thermal fracturing of the salt may occur and degrade the integrity of the salt cavern. For this reason, LNG at very low temperatures cannot be stored in conventional salt caverns. If a fluid is pumped into a salt cavern and the fluid is above 140ºF it will encourage creep and decrease the volume of the salt cavern.

[0016] The present invention is referred to as the Bishop One-Step Process. It eliminates the need for expensive cryogenic storage tanks. The present invention uses a high pressure pumping system to raise the pressure of the LNG from about one atmosphere to about 1200 psig or more. This increase in pressure changes the state of the LNG from a cryogenic liquid to dense phase natural gas (DPNG). The present invention also uses a unique heat exchanger called the Bishop Process heat exchanger mounted onshore or offshore to raise the temperature of the DPNG from about -250ºF to about +40ºF so the warmed DPNG can be stored in an uncompensated salt cavern. In addition, the DPNG can also be stored in other types of salt strata, provided the formation does not leak. All of these techniques eliminate the need for conventional surface mounted cryogenic storage tanks. Subsurface storage is more secure than conventional systems as demonstrated by the use of a salt cavern storage system by the Strategic Petroleum Preserve. Once the LNG has been warmed and converted from a liquid to DPNG using the present invention, it can also be transferred through a throttling valve or regulator into a pipeline for transport to market. In an alternative embodiment, a conventional vaporizer system can also be